connected. This was done to eliminate a sharp corner at the attachment point, in order to prevent stress concentrations. Four noded quadrilateral plane strain elements, with reduced integration were used for the sheet. The sheet had three elements E* through the thickness, and 3800 elements along the length. Contact surfaces were established on the outer surface of the reel and inner surface of the sheet, and self-contact surfaces were established on the sheet to handle the contact between overlapping layers.

The reel was modeled as a rigid body, and the sheet was modeled as an elastic material with the properties of polypropylene at room temperature. The elastic modulus was taken to be 1.637 GPa, Poisson's ratio was taken as 0.40, and the density was taken to be 900 kg/m^3.

An explicit dynamic analysis was performed with a time-varying force applied to the nodes on the top surface of the outer layer of the sheet. The reel was constrained from translation and rotation, and the nodes on the bottom surface of the inner layer of the sheet were constrained from translation. A force of 10.0 N was applied to each node in the top three rows on the outer layer of the sheet. The rise time for the force was 10.0 seconds, and the analysis was conducted for a total time period of 20.0 seconds, in order to achieve a steady state solution. The density of the sheet material was scaled by a factor of 10^4 in order to achieve a reasonable time step.

Figure 14B shows the reference and deformed configurations of the structure after 11.0 seconds. The deformed view shows the length increasing as the layers come into contact, and the gap between layers disappears.

Figure 14C shows a plot of the stresses, σ_{11} and σ_{22}, in the sheet at 11.0 seconds. A local coordinate system was used so that σ_{11} is along the axis of the sheet, and σ_{22} is through

the thickness. When considering the wound structure, the stresses σ_{11} and σ_{22} correspond to stresses in the circumferential and radial directions, respectively. The main units used in the analysis were kg, mm, and seconds, so the magnitude of stresses shown in Figure 14C needs to be multiplied by 1000 to obtain Pascals. The maximum circumferential stress is observed in the outer layer, and the value decays to zero at the inner layer. To compute the stresses for the plane strain condition, an effective width out of the plane of 1.0 mm is assumed. Using the total maximum applied force of 120 N, a simple static calculation of force divided by area for a rod gives a longitudinal stress of 40.0 MPa.

The distribution of radial stress shows the maximum stress occurring in the inner layer adjacent to the reel surface, and zero stress in the outer layer. The pattern of stress observed is reasonable for the type of load applied, but it does not show a strong interaction between the compressive forces and the circumferential stress. In the actual winding process, each layer of material added to the reel is under an applied tension, so the stresses evolve from the inner layer outwards. The model, however, has the stress starting at the outer layer due to the applied tension, and then propagating inwards towards the reel.

In order to obtain a more accurate representation of the problem, a dynamic winding model was developed. This model included a reel with a long sheet of material attached to the side. The outer diameter of the reel was 240.0 mm, and the thickness and length of the sheet was 3.0 and 7000.0 mm, respectively. The length of the sheet was chosen to make approximately ten wraps around the reel. The model and finite element mesh used are shown in Figure 15A. The surface of the reel was created using a spiral so there would be a slight offset where the sheet is attached. This was done to eliminate a sharp corner at the attachment point, in order to prevent any stress concentrations. The nodes on the bottom

edge of the sheet were made coincident with the nodes on the reel surface to create a perfect bond. Four noded quadrilateral plane strain elements E, with reduced integration, were used for the sheet 151. The sheet 151 had three elements through the thickness, and 4000 elements along the length. Contact surfaces were established on the outer surface of the reel and inner surface of the sheet, and self-contact surfaces were established on the sheet to handle the contact between overlapping layers. The reel was modeled as a rigid body, and the sheet was modeled as an elastic material with the properties of polypropylene at room temperature. The elastic modulus was taken to be 1.637 GPa, Poisson's ratio was taken as 0.40, and the density was taken to be 900 kg/m^3.

An explicit dynamic analysis was performed with a force applied to the end of the sheet, followed by the application of angular velocity to the reel. The reel was constrained from translation, but was allowed to rotate under the action of the prescribed angular velocity.

In the computations, a force of 10.0 N was applied to the first ten horizontal rows of nodes at the top end of the sheet. The ramp time on the force was 2.0 seconds, and the angular velocity started at 3.0 seconds and attained its steady value by 5.0 seconds. The force was applied before the angular velocity to allow the transients in the sheet to die out before winding occurred. An angular velocity of 9.7 rad/sec was chosen to achieve an approximate linear velocity of 70.0 m/min for the sheet. The variation of the force and velocity in time is depicted in Figure 15B. The density of the sheet material was scaled by a factor of 10^4 in order to achieve a reasonable time step.

Figure 15C shows a plot of the circumferential and radial stresses in the wound sheet at 10.43 seconds. The magnitude of stress needs to be multiplied by 1000 in order to obtain units of Pascals. This plot shows a snapshot of the stresses at the time the sheet is almost